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Performance and Emission Characteristics of Diesel and Jatropha Oil Blends in a Direct Injection Variable Compression Ratio Ignition Engine

B. De† and R. S. Panua

Department of Mechanical Engineering, National Institute of Technology Agartala, India

†*Corresponding Author Email: biswajiyphd@gmail.com*

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ABSTRACT

The rapid depletion of conventional fuel and fluctuation of Diesel price in the global market have promoted research for alternative fuels for Diesel engine. Among the different alternative fuels, vegetable oil having fuel properties similar to Diesel has an acceptable engine performance. Vegetable oils are producing less CO_2 emissions to the atmosphere because of their agricultural origin and less carbon content compared to mineral Diesel. It also reduces import of petroleum products. In the present investigation, an experimental study is carried out on an I.C.E laboratory in single cylinder, four-stroke VCR, direct injection Diesel engine to analyze the performance and emission characteristics of pure Diesel and Jatropha oil-Diesel blended fuels with various blend ratios. The measurements are recorded for the compression ratio 16, 17 and 18 with varying load from idle to rated load of 5.2 kW. Comparative results are given at constant engine speed, variable compression ratio and different engine BMEP for baseline Diesel and Jatropha oil-Diesel blended fuels revealing the effect of Diesel and Jatropha-Diesel blended fuels' combustion on engine performance and exhaust emissions. The results show that for same blend, performance of the engine is improved considerably with the increase in CR. Thermal efficiency, exhaust gas temperature and emission parameters such as NO_X, HC and CO at CR 18 with blends containing up to 30% (by volume) Jatropha oil is comparable to that of diesel fuel. So, blends containing up to 30% (by volume) Jatropha oil at CR 18 can be honestly used as an alternative fuel without any engine modification.

Keywords: Jatropha oil; Blending; Viscosity; Concentration; Performance; Emission analysis.

NOMENCLATURE

B100	100% jatropha oil	CO	carbon monoxide
B20	20% jatropha oil and 80% diesel oil in blends	CR	compression ratio
		EGT	exhaust gas temperature
B30	30% jatropha oil and 70% diesel oil in blends	HC	hydrocarbon
		ICE	internal combustion engine
B40	40% jatropha oil and 60% diesel oil in blends	J10	10% jatropha oil and 90% diesel oil in blends
BMEP	brake mean effective pressure	NO_X	oxides of nitrogen
BSFC	brake specific fuel consumption	VCR	variable compression ratio
BTE	brake thermal efficiency		

1. INTRODUCTION

Bio-diesel production is not something new, because the concept of using vegetable oil as fuel dates back to 1895. Rudolf Diesel developed the first Diesel engine which was run with vegetable oil in 1900. The first Diesel engine was run using groundnut oil as fuel (Bijalwan *et al.* 2006). Thomas *et al.* (1993) explained that vegetable oils contain significant amounts of oxygen. Its ignition characteristics are poor for cold engine start-up, misfire, and ignition delay which leads to incomplete combustion, e.g. deposit formation, carbonization of injector tip, ring sticking, lubricating oil dilution and degradation, polymerization during storage. Carbon deposits around the nozzle orifice, upper piston ring grooves and on piston rings are the main problems during the use of vegetable oil as fuel. Ramadhas *et al*. (2005) described that a compression ignition engine running with rubber seed oil as a surrogate fuel results in elevated carbon dumps inside combustion chamber compared to that of diesel-fuelled engine. Recurrent cleaning of fuel filter, pump and the combustion chamber are needed for rubber seed oil blend fuel. Karosmanoglu *et al*. (2000) performed tests on a solitary cylinder, straight injection air-cooled Diesel engine utilizing sunflower oil as a substitute fuel and established that there was no considerable variation in power output and fuel consumption. He *et al*. (2003) described that there is an excellent prospective for the most of the vegetable oils as surrogate fuel for short-term engine performance tests and resulted in increased volumetric fuel consumption and BSFC. Babu *et al*. (2003) explained that compression ignition engine operating with vegetable oil as substitute fuel is produced a satisfactory engine performance and exhaust gas emission level for short-term operation only. But for long term operation they produced carbon dump buildup in the cylinder and sticking of piston rings. De and Panua (2014), in their study considered a simplified evaporation and combustion model, fuelled with Diesel and different Jatropha oil blends with Diesel implemented in CFD code Fluent. During the experiments, it was found that excellent concurrences of pressure trace are accomplished involving the experimental and predicted data for all the tested fuels. Therefore, the main objective of the present study is to decrease the viscosity of Jatropha curcas oil by blending with diesel and to evaluate the engine performance and emission characteristics without any substantial hardware modifications of the existing Diesel engine.

2. EXPERIMENTAL SETUP

The engine used for present investigation is a four stroke, water cooled, single cylinder VCR, direct injection vertical Diesel engine. Labview based Engine Performance Analysis software package "Engine soft LV" is provided for on line performance evaluation. The engine is running at a rated speed of 1500 rpm. Fresh lubricating oil was filled in the engine sump tank before starting the experiments. The engine is connected to eddy current type dynamometer for loading. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. The schematic Diagram of the experiment set up is shown in Fig. 1. The technical specification of the engine is given in Table 1.The set up has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test (Diesel and Jatropha oil), manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Several blends of varying concentrations ranging from 0% (mineral diesel) to 100% (Jatropha oil) through 10%, 30%, 50%, 80% are prepared. The engine is started with diesel and once the engine warm-up; it is switched over to blended oil. For switching the engine from Diesel to blended oil, a two-way valve was provided on the control panel. One end of the valve is connected to Jatropha oil, while the other is connected to diesel. Fuel from valve enters into the engine through fuel measuring unit, which enables the volumetric flow of the fuel to be measured easily. Engine start at no load at CR of 16 and varying the load from idle to rated load of 5.2 kW in a number of steps and a set of reading is obtained for 10%, 30%, 50%, 80% and 100% (Jatropha oil) and another set of readings are recorded for the operation of the engine in Diesel fuel mode. Fuel consumption, rpm, exhaust temperature, NO_X, CO and power output are measured. Similar set of readings are recorded for CR of 17 and 18 by tilting cylinder head arrangement for 10%, 30%, 50%, 80%, 100% (Jatropha oil) and diesel.

Table 1 Specification of the test engine.

S. No	*Parameters*	*Specification*
1.	General Details	Single cylinder, four stroke compression ignition engine, constant speed, vertical, water cooled, direct injection
2.	Stroke	110 mm
3.	Bore	87.5 mm
4.	Displacement	661 cc
5.	Compression ratio	17.5
6.	Rated output	5.2 kW
7.	Rated speed	1500 rpm

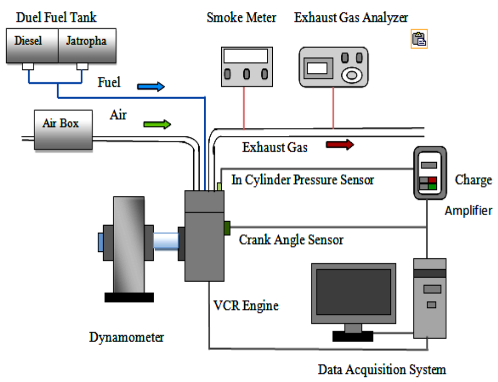


Fig. 1. Schematic Diagram of experimental setup.

The emissions (NO_X, CO concentrations) are recorded by using Gas Analyzer (AVL Di Gas 444) and the opacity is recorded by smoke meter (AVL 437). To ensure the accuracy of the measured values, the gas analyzer is calibrated before each measurement. For all settings, the emission values and the other values are recorded thrice and a mean of these is taken for comparison. The performance and emission of the engine at different loads are evaluated in terms of BSFC, brake thermal efficiency and emissions of carbon monoxide, un-burnt hydrocarbon and oxides of nitrogen with exhaust gas opacity and temperature.

Table 2 Fuel properties of Diesel and Jatropha oil blends.

Fuel blend	*Density (kg/m^3)*	*Viscosity at 40^0 C (cSt)*	*CV (MJ/kg)*	*Flash point (^{0} C)*	*Fire point (^{0} C)*
Diesel	841	2.575	44.864	72	104
J10	846.3	5.88	44.251	86.5	110.2
J30	861.4	12.54	43.027	114.4	148.6
J50	875.6	19.36	41.761	146.3	181.3
J80	898.4	28.65	39.896	189.5	232.6
J100	917.5	36.63	38.6355	230	275
Testing procedure	ASTM D 1298	ASTM D445	ASTM D 240	ASTM D93	ASTM D93

Table 3 List of instruments and the range, accuracy and percentage uncertainties

Instruments	*range*	*Accuracy*	*Percentage uncertainties*
Gas analyzer	NO_X 0-5000 ppm HC 0-2000 ppm CO 0-10% CO_2 0-20%	±10 ppm ±15 ppm ±0.02% ±0.028%	±0.1 ±0.15 ±0.02 ±0.03
Smoke meter	BSN 0-10	±0.2	±0.12
EGT indicator	0-900 ^{0}C	±0.1 ^{0}C	±0.13
Load indicator	0-100 kg	±0.1 kg	±0.14
Presure picup	0-110 bar	±0.1 bar	±0.1
Crank angle encoder		±0.1^0	±0.1

3. Result And Discussions

The important fuel properties of Diesel and Jatropha oil blends are given in Table 2.

In the present investigations, to eliminate the flow/atomization related problems of the vegetable oil as surrogate fuel in Diesel engines, the viscosity of vegetable oil is reduced by blending the oil with mineral Diesel. Table 3 describes list of instruments and the range, accuracy and percentage uncertainties. The performance and emission characteristics of the Jatropha carcass vegetable oil and its different blends with diesel fuel operation are compared with baseline diesel; and are presented in Figures 2-5.

3.1 Brake Thermal Efficiency

Fig.2 shows the variation of BTE with BMEP at VCR for pure diesel, Jatropha oil and its different blends. For Jatropha oil and its different blends, the BTE for Jatropha blended fuel is lesser than that of pure Diesel operation from no load to full load conditions and this difference is higher at full load and follows almost the same trend as at CR of 16 with slightly higher CR of 17 and 18.

It can be noticed from figure 2(a) that at CR of 16, BTE of Jatropha oil and its different blends are lesser than Diesel mode by 1.22%, 3.144%, 4.23%, 5.28% and 6.837% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at BMEP of 4.34 × 10^5 N/m^2 and by 1.82%, 2.75%, 4.34%, 5.32% and 6.34% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at BMEP of 5.67 × 10^5 N/m^2.

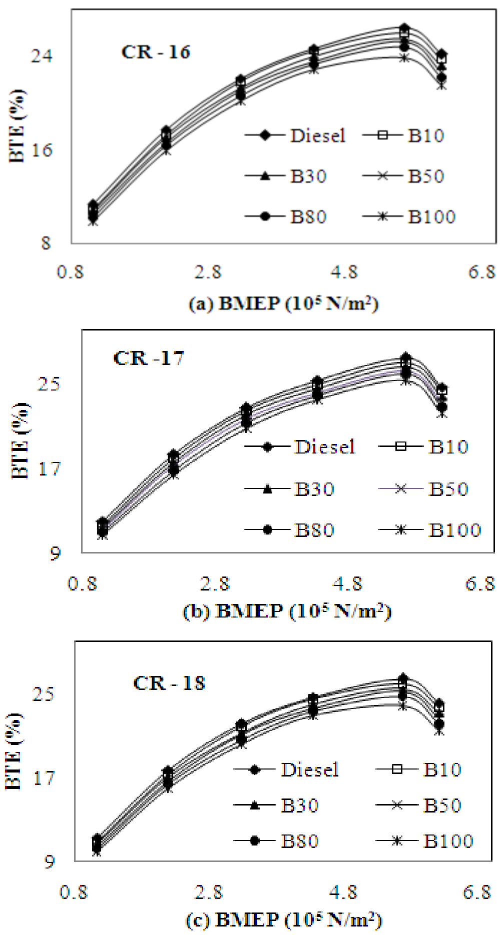


Fig. 2. Brake thermal efficiency with BMEP for diesel and different Jatropha oil blends at CR 16, 17 and 18.

Figure 2(c) shows that at CR of 18, BTE of Jatropha oil and its different blends are lesser than Diesel mode by 1.81%, 3.21%, 4.62%, 6.24% and 7.65% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at BMEP of 4.34 × 10^5 N/m^2 and by 1.37%, 3.21%, 4.24%, 5.34% and 6.52% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at BMEP of 5.67 × 10^5 N/m^2. BTE of multi fuel engine is lesser at low loads but significantly high at higher engine loads because at lower loads, the percentage of fuel is higher compared to inducted fresh air resulting in incomplete combustion. At higher engine loads, fuel-air ratio increases, resulting in complete combustion and increase in brake thermal efficiency. Higher viscosity and poor volatility of vegetable oils lead to their poor atomization and combustion characteristics. These factors are accounted for the variation of brake thermal efficiency for duel fuels. Ramadhas *et al*. (2005) also obtained similar results at fixed CR.

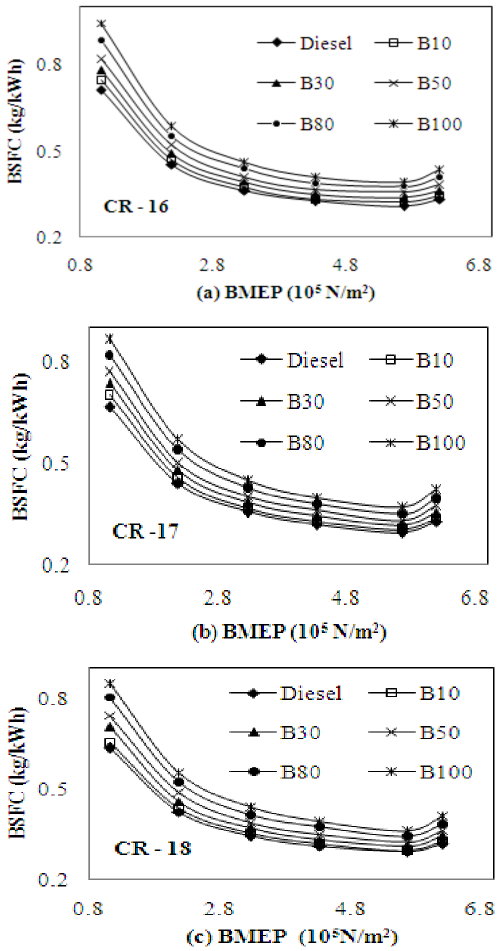


Fig. 3. Brake Specific Fuel Consumption with BMEP for diesel and different Jatropha oil blends at CR 16, 17 and 18.

3.2 Brake Specific Fuel Consumption

BSFC means the rate of fuel consumption per unit output. Figure 3 shows the consumption of the fuel in kg/kWhr of the brake output of the engine. The observations for BSFC for base diesel and dual fuel modes at CR of 16, 17 and 18 and for 10%, 30%, 50%, 80%, and 100% Jatropha oil concentration in the blends are recorded and represented graphically for analysis. From Figure 3(a), it is observed that at CR of 16, BSFC for Jatropha oil blends is higher than that of Diesel fuel mode by 2.12%, 4.32%, 5.21%, 6.28% and 7.21% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at BMEP of 4.34 × 10^5 N/m^2 and by 2.13%, 4.12%, 5.23%, 6.54% and 7.26% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at BMEP of 5.67 × 10^5 N/m^2.

Figure 3(c) shows that at CR of 18, BSFC for duel fuel mode is higher than diesel fuel mode by 2.24%, 4.28%, 5.34%, 6.87% and 7.03% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at BMEP of 4.34 × 10^5 N/m^2 and by 2.12%, 4.32%, 6.52%, 7.66% and 9.78% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at BMEP of 5.67 × 10^5 N/m^2. It is also observed that BSFC is lower for neat Diesel mode and increases gradually with the increase of Jatroha oil concentration in dual fuel modes and follow almost the same trend as at CR 16 with slightly higher value at CR 17 and 18. These may causes due to higher viscosity and poor volatility of vegetable oils. The BSFC is found to decrease with the increase of engine compression ratio as shown in Fig. 3.

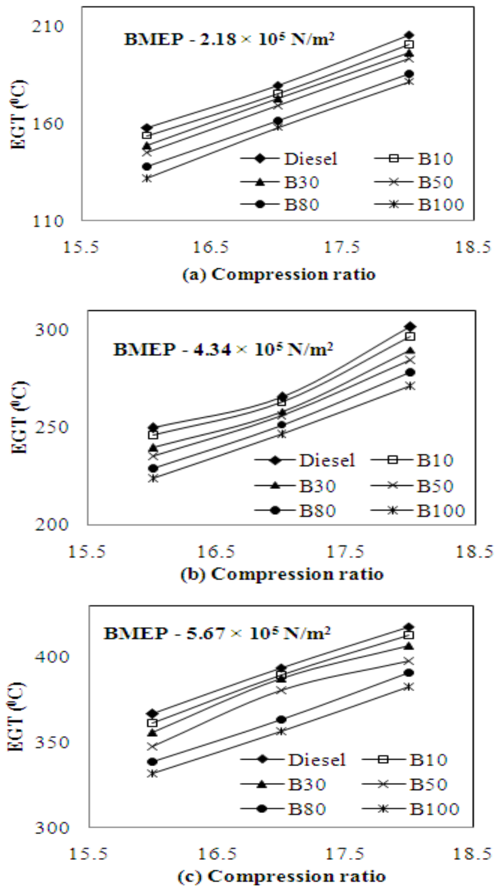


Fig. 4. Effect of compression ratios on Exhaust Gas Temp for Diesel and different Jatropha oil blends at CR 16, 17 and 18.

3.3 Exhaust Gas Temperature

Figure 4 represents the effect of varying compression ratio and Jatropha oil blends on EGT of the engine cylinder for Diesel and blending fuel modes at BMEP of 2.18 × 10^5 N/m^2, 4.34 × 10^5 N/m^2, 5.67 × 10^5 N/m^2. It can be shown from figure 4, that EGT increases with increase of engine load and compression ratio both for Diesel and blended fuel modes.

EGT is higher for Diesel and decreased with the increase in Jatropha oil percentage in the blends. Figure 4(b) shows that at BMEP of 4.34 × 10^5 N/m^2, EGT for blended fuel mode is lesser than Diesel fuel mode by 2.1%, 3.24%, 4.56%, 5.22% and 6.47% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 2.3%, 3.63%, 4.83%, 5.11% and 6.41% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18. Figure 4(c) shows that at BMEP of 5.67 × 10^5 N/m^2, EGT for blended fuel mode is lesser than Diesel fuel mode by 2.65%, 3.76%, 4.13%, 6.12% and 6.83% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 2.31%, 3.27%, 4.66%, 5.33% and 6.24% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18. Karosmanoglu *et al*. (2000) also observed the same results at fixed compression ratio.

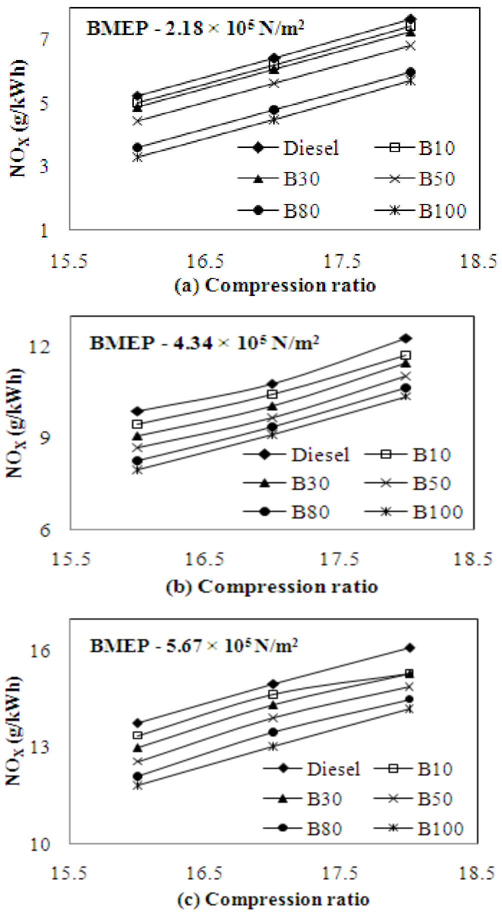


Fig. 5. Effect of compression ratio on NO_X emissions for diesel and different Jatropha oil blends at CR 16, 17 and 18.

3.4 NO_X Emissions

Figure 5 represents the effect of changing compression ratio and Jatropha oil blends on NO_X emission formed inside engine cylinder for diesel and blending fuel modes at BMEP of 2.18 × 10^5 N/m^2, 4.34 × 10^5 N/m^2, 5.67 × 10^5 N/m^2. It can be shown from figure 4 that NO_X emission increases with increase in engine BMEP and compression ratio both for Diesel and blended fuel modes. NO_X emissions are higher for baseline Diesel and decreased with the increase in Jatropha oil percentage in the blends.

Figure 5(b) shows that at BMEP of 4.34 × 10^5 N/m^2, NO_X emissions for blended fuel mode is lesser than Diesel fuel mode by 2.6%, 3.18%, 4.56%, 5.57% and 6.17% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 2.23%, 3.43%, 4.78%, 5.81% and 6.46% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18. Figure 5(c) shows that at BMEP of 5.67 × 10^5 N/m^2, NO_X emissions for blended fuel mode is lesser than diesel fuel mode by 2.52%, 3.56%, 5.13%, 5.89% and 6.73% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 2.32%, 3.57%, 4.74%, 6.12% and 6.76% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18. NO_X formation is mainly depends on high peak temperatures and availability of oxygen in the combustion chamber. Babu *et al*.(2003) also observed the same results at fixed CR.

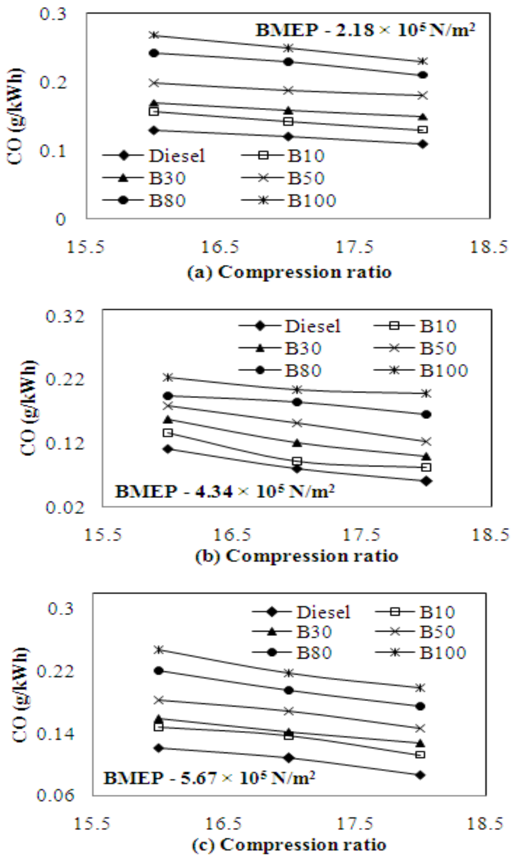


Fig. 6. Effect compression ratio on CO emissions for diesel and different Jatropha oil blends at CR 16, 17 and 18.

3.5 CO Emissions

Figure 6 shows the effect of changing compression ratio and Jatropha oil substitution rates on Carbon monoxide emission concentration in diesel and dual fuel modes at BMEP of 2.18 × 10^5 N/m^2, 4.34 × 10^5 N/m^2, 5.67 × 10^5 N/m^2. CO emissions are less at low engine BMEP but considerably increase at high engine BMEP. It increases with increase of Jatropha oil concentration in the blended fuel mode compared to that of baseline Diesel. It also decreases with the increase in compression ratio. Figure 6(b) shows at BMEP of 4.34 × 10^5 N/m^2, CO emission for blended fuel mode is higher than Diesel fuel mode by 2.93%, 4.15%, 4.87%, 5.73% and 6.21% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 2.25%, 3.26%, 3.49%, 5.1% and 5.94% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18.

Figure 6(c) shows that at BMEP of 5.67 × 10^5 N/m^2, CO emissions for duel fuel mode is higher than Diesel fuel mode by 2.73%, 4.31%, 4.89%, 5.31% and 6.13% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 2.76%, 3.39%, 4.05%, 5.65% and 6.53% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18. CO is an intermediate product in the combustion of hydrocarbons. It is formed mainly due to incomplete combustion, which is exacerbated by lack of oxidants, temperature and residence time.

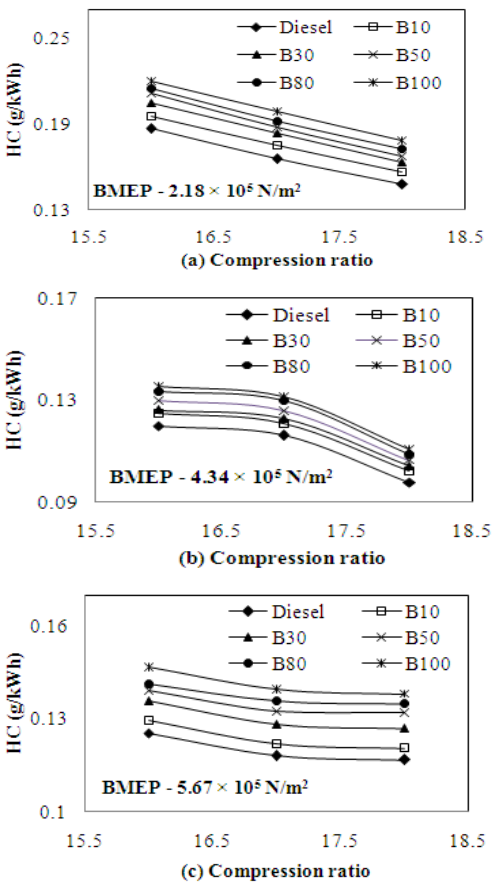


Fig. 7. Effect compression ratio on HC emissions for diesel and different Jatropha oil blends at CR 16, 17 and 18.

3.6 HC Emissions

Figure 7 depicts the variation of unburned HC emission for Diesel and blended fuel modes (with 10%, 30%, 50%, 80% and 100% Jatropha oil blends) at BMEP of 2.18 × 10^5 N/m^2, 4.34 × 10^5 N/m^2, 5.67 × 10^5 N/m^2 with three compression ratios of 16, 17 and 18 respectively. It is very clear from the figures that HC emission in the exhaust decreases with load applied for both diesel and blended fuel modes but HC emission is higher for blended fuel mode than pure Diesel mode and further increase with the increasing in Jatropha oil concentration in the blended fuel operation. It also decreases with the increase in compression ratio of the test engine.

Figure 7(b) shows at BMEP of 4.34 × 10^5 N/m^2, HC emission for blended fuel mode is higher than Diesel fuel mode by 3.1%, 4.32%, 4.85%, 6.05% and 6.74% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 2.83%, 4.16%, 4.93%, 5.27% and 6.35% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18. Figure 7(c) shows that at BMEP of 5.67 × 10^5 N/m^2, HC emission for duel fuel mode is higher than Diesel fuel mode by 2.92%, 3.63%, 4.87%, 5.51% and 6.17% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 2.37%, 4.22%, 5.17%, 5.76% and 6.23% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18. Hydrocarbons in exhaust consist of either decomposed fuel molecules or recombined intermediate compounds.

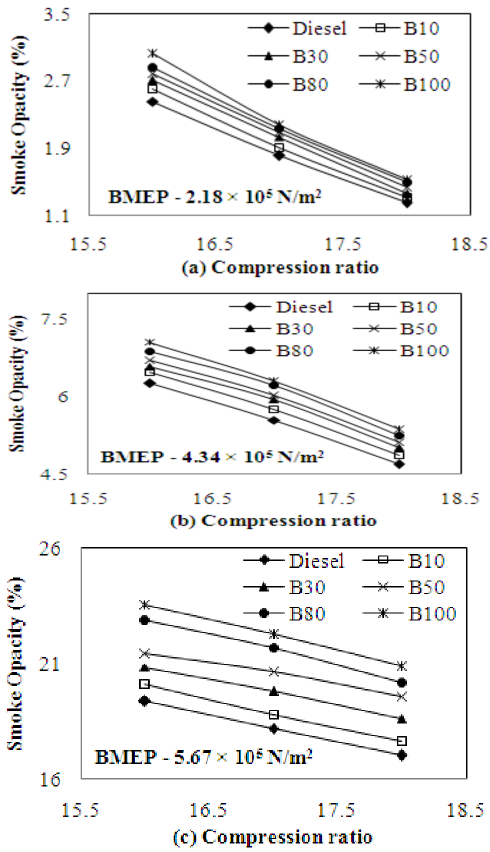


Fig. 8. Effect of compression ratio on Smoke opacity for diesel and different Jatropha oil blends at CR 16, 17 and 18.

3.7 Smoke Emissions

The variations of smoke opacity as a function of BMEP are given in figure 8 at variable compression ratios for both Diesel fuel and duel fuels operation.

From figure 8, it is obvious that smoke opacity increased with increase in Jatropha oil percentage in the blends and with the increase in CR. Figure 8(b) shows at BMEP of 4.34 × 10^5 N/m^2, smoke opacity for blended fuel mode is higher than diesel fuel mode by 2.37%, 3.38%, 4.65%, 5.87% and 6.58% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 2.36%, 3.54%, 5.08%, 5.85% and 6.83% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18. Figure 8(c) shows that at BMEP of 5.67 × 10^5 N/m^2, smoke opacity for blended fuel mode is higher than Diesel fuel mode by 3.02%, 4.26%, 5.92%, 6.37% and 6.83% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 16 and by 3.11%, 4.39%, 5.48%, 6.34% and 8.32% with 10%, 30%, 50%, 80% and 100% Jatropha oil blends at CR 18. The higher viscosity and poor volatility of vegetable oils lead to their poor atomization and combustion characteristics resulting in higher HC emission.

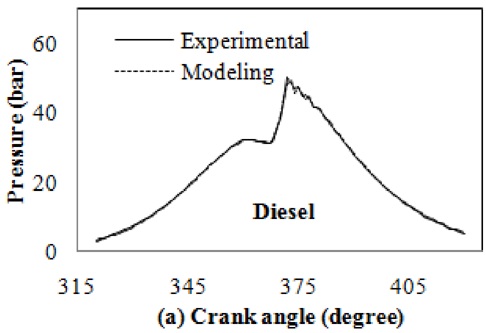
3.8 Validation

The data of experimental tests and the results from parallel simulation (using Fluent 6.3) are judged against one another in terms of pressure traces (De and Panua 2014, 2015).

3.8.1 Cylinder Pressure Trace

Figure 9 illustrates the simulated and experimental in-cylinder pressure trace with respect to CA for baseline diesel and different blending fuels. The predicted pressure data explains a good agreement with experimental data for both diesel and blending fuels, even though there is still some dissimilarity which can be seen in Fig.9.

These disagreements could be associated with the experimental uncertainties in input parameters to the computations such as the precise injection duration, start of injection timing and gas temperature at IVC. At high engine load, huge amount of fuel is injected (constant rpm engine), hence the heat released in the cylinder and in-cylinder pressure (P_{MEP}) is high. Diesel fuel is a light fuel and is easily atomized, vaporized and mixed with air raising its self-ignition temperature and reduces delay period.



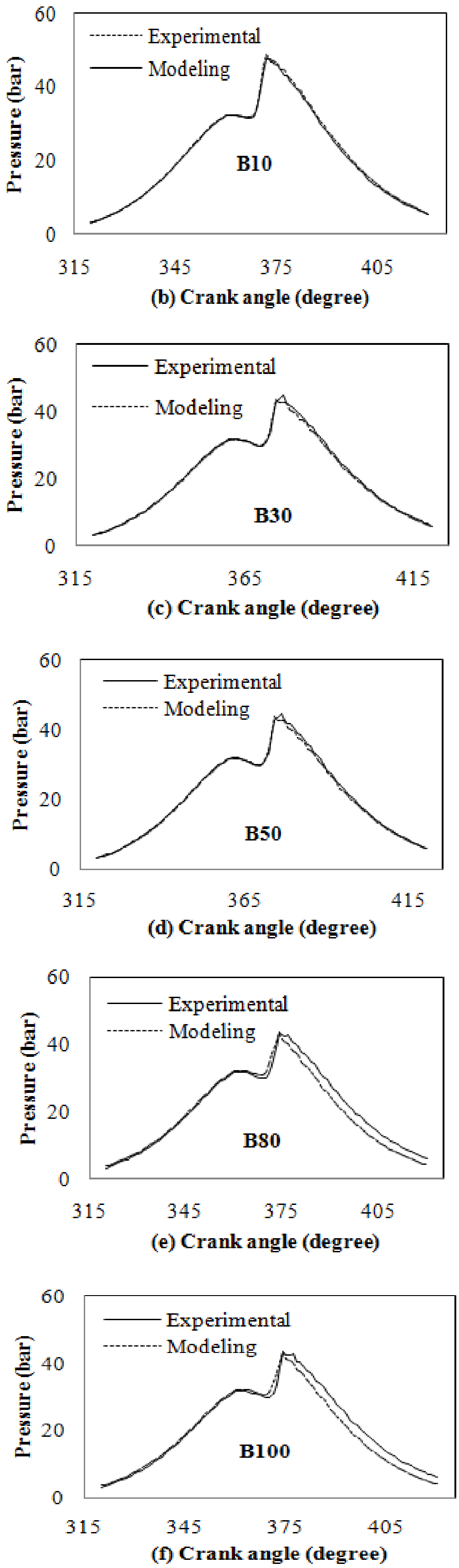


Fig. 9. Comparison of in-cylinder pressure between simulation and experiments for Diesel and different blending fuels.

Improved combustion of the fuel-air mixture is increased the in-cylinder pressure (P_{MEP}). On the other hand, Jatropha oil blends, are viscous fuel increases the delay period resulting in lower in-cylinder pressure (P_{MEP}) compared to that of diesel fuel. Lower calorific value of Jatropha oil blends also can be accounted for producing lower peak temperature and pressure of engine cylinder evaluated to that of diesel fuel.

4. CONCLUSIONS

In the present study, VCR engine is fuelled with Jatropha oil blends as alternative fuels and conclusions of the study are given below:

- Brake thermal efficiency with Jatropha oil and its blends is found to be lesser than that of pure Diesel operation from no load to full load conditions and this disparity is higher at full load condition. For same blend, performance of the engine is improved considerably with the increase in CR.
- With the increase in brake power and CR, the EGT increases for all the tested fuels.
- NO_X level increase with increase in engine BMEP and CR for both diesel and blended fuel operations.
- CO emission is lesser at low engine BMEP but increases significantly at high engine BMEP and increases with raise in Jatropha oil concentration in the blends compared to that of Diesel and also decreases with increase in CR.
- Thermal efficiency, exhaust gas temperature and emission parameters such as NO_X and CO at CR 18 with blends containing up to 30% (by volume) Jatropha oil is comparable to that of Diesel fuel.
- So, blends containing up to 30% (by volume) Jatropha oil at CR 18 can be honestly used as an alternative fuel without any engine modification.
- Good level of agreement is reported between computational and measured data for engine pressure trace for all the test cases, even though there are still some dissimilarities are found between experimental and computational results. These disagreements are found because of uncertainties in input parameters to the computations such as the precise injection duration, start of injection timing and gas temperature at IVC.

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REFERENCES

Babu, K. and G. Devarajane (2003). Vegetable oils and their derivatives as fuels for CI engines: an overview. *Society of Automotive Engineers*, 406-418.

Bijalwan, A., C. M. Sharma and V. K. Kedial (2006). Bio-diesel revolution*. Science reporter* 14-17.

De, B. and R. S. Panua (2014). CFD Modeling and validation of combustion in direct injection Compression Ignition engine fuelled with Jatropha oil blends with Diesel. *Frontiers in Heat and Mass Transfer*.

De, B. and R. S. Panua (2015). Performance and emission characteristics of Diesel and vegetable oil blends in a direct-injection engine. *Journal of the Brazillian Society of Mechanical Sciences and Engineering.*

He, Y. and Y. D. Bao (2003). Study on rapeseed oil as alternative fuel for a single cylinder diesel engine*. Renewable Energy* 28, 1447–1453.

Karosmanoglu, F., G. Kurt and T. Ozaktas (2000). Long term CI engine test of sunflower oil, *Renewable Energy* 19, 219-221.

Ramadhas, A. S., S. Jayaraj and C. Muraleedharan (2005*).* Characterization and effect of using rubber seed oil as fuel in the compression ignition engines. *Renewable Energy*, 30, 795–803.

Thomas, R. W. and B. O. Maurin (1993*). Identification of chemical change occurring during the transient injection of selected vegetable oils*, 201-210.